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AN ADVANCED NDE TECHNIQUE FOR AGILE MANUFACTURING

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13. ABSTRACT *(Maximum 200 Words)*

A Konoscope™ volumetric x-ray computed tomography (CT) system (the Konoscope™) was developed. Unlike conventional CT systems, which acquire data one slice at a time, the Konoscope™ acquires all the necessary data at one time. This approach significantly accelerates the collection of the CT data required for image production, especially for high-resolution scanning. The Konoscope™ employs an x-ray cone beam and an area detector, rather than the fan beam and linear detector used in conventional CT systems. Technological advancements made during the project and incorporated in the Konoscope™ include: a bright x-ray source using an ARACOR diamond anode bright anode transmission target (BRATT™); a high-performance area detector; a helical scan geometry for acquiring volumetric CT data; and the parallel processing of optimized reconstruction software for timely reconstruction of large, volumetric data sets. The Konoscope™, which is housed in a fully shielded cabinet, can inspect an object 100 mm to 200 mm in diameter at a maximum resolution of 250 µm. Part dimensions can be measured with an estimated accuracy of 25 µm. Creating volumetric CT images with the Konoscope™ is significantly faster than with conventional 2-D CT systems. The Konoscope™ is capable of supporting the most demanding CT applications, such as metrology and reverse engineering, which require data with the highest accuracy and resolution. The Konoscope™ is uniquely qualified to nondestructively capture 3-D part geometry, which is an essential component of agile manufacturing.

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ACKNOWLEDGEMENT

The majority of the development of the Konoscope™ x-ray computed tomography system was performed under a cooperative agreement with the Defense Advanced Research Projects Agency (DARPA) and the Air Force Research Laboratory (AFRL) under Air Force Contract Number F33615-95-2-5239. Additional support was provided by the State of California Competitive Technologies Program (C95-0127), the National Science Foundation (NSF) (DMI-962-8968), and ARACOR.

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1.0 EXECUTIVE SUMMARY

In this project, ARACOR developed the Konoscope™ volumetric x-ray computed tomography (CT) system (the Konoscope). Unlike conventional CT systems, which acquire data one slice at-a-time, the Konoscope acquires all the necessary data at one time. This approach significantly accelerates the collection of the CT data required for image production, especially for high-resolution scanning. The Konoscope employs an x-ray cone beam and an area detector, rather than the fan beam and linear detector used in conventional CT systems. Technological advancements made during the project and incorporated in the Konoscope include:

1. A bright x-ray source using an ARACOR diamond anode BRATT™ (BRight Anode Transmission Target) target
2. A high-performance area detector
3. A helical scan geometry for acquiring volumetric CT data
4. The parallel processing of optimized reconstruction software for timely reconstruction of large, volumetric data sets.

The Konoscope, which is housed in a fully shielded cabinet, can inspect an object 100 mm to 200 mm in diameter at a maximum resolution of 250 µm. Part dimensions can be measured with an estimated accuracy of 25 µm. Creating volumetric CT images with the Konoscope is significantly faster than with conventional 2-D CT systems. In one day, three parts can be scanned and 512 x 512 x 512 volumetric images produced. Even a 1024 x 1024 x 1024 scan of one part can be completed in one day. The Konoscope is capable of supporting the most demanding CT applications, such as metrology and reverse engineering, which require data with the highest accuracy and resolution. The Konoscope is uniquely qualified to nondestructively capture 3-D part geometry, which is an essential component of agile manufacturing.

2.0 MOTIVATION

This project was motivated by the need to develop a practical CT system to support high-resolution imaging applications, especially metrology and reverse engineering. With conventional 2-D CT, which acquires data one slice at-a-time, scanning an entire part at the highest available resolution can be a time-consuming process. Attempts have been made at developing 3-D (volumetric) CT systems, where an entire volume of data is acquired at one time, rather than slice-by-slice. Although these initial volumetric CT systems were faster than 2-D scanners, they could not achieve the required resolution. A CT system was needed with the resolution of 2-D CT and the inspection speed of volumetric CT. The Konoscope developed in this project is such a system.

2.1 AGILE MANUFACTURING

As its name implies, agile manufacturing has been defined as the ability to make any part at any time in any quantity for any customer. The key to achieving agile manufacturing is the development of practical, fully-integrated computer-based capabilities to define, design, engineer, and manufacture parts, including:

- Accurately and rapidly define 3-D part geometry (inspection).
- Compare part geometry with design requirements (metrology).
- Create an accurate digital computer aided design (CAD) model of the part.
- Predict part response to operational loads and environments using computer aided engineering (CAE).
- Reproduce a part from its CAD model using computer aided manufacturing (CAM) and rapid prototyping techniques.

One application of agile manufacturing is the production of spares for aging aircraft. The U.S. Air Force has a large number of older aircraft that are expected to be the backbone of the total operational force for the foreseeable future. To support the extended lifetimes for these aircraft, the spare parts pool must be replenished. Furthermore, an initial complement of spares must be established for parts that were never envisioned for replacement. When spares need to be fabricated, they are typically purchased from the Original Equipment Manufacturer (OEM) or another third-party vendor qualified to produce the part.

Production of spares for aging aircraft is often problematic because the required technical data packages (drawings and/or CAD files) for needed spare parts are unavailable or incomplete. When the technical data package is missing or incomplete, reverse engineering can be used to 1) measure the part to define its three-dimensional geometry, 2) create engineering drawings and/or a CAD model, and 3) fabricate additional parts. In conventional reverse engineering, which can be time consuming and labor intensive, the external surface of a part is measured using manual techniques and machines, such as a coordinate measuring machine (CMM) or a laser scanner. A part must be destroyed and sectioned to measure its internal geometry.

2.2 CT-BASED REVERSE ENGINEERING

ARACOR has developed CT-based Reverse Engineering, Metrology, and Part Production (REMAPP™) technology. Using this technology, CT data are acquired from the entire part and converted to a 3-D "point cloud," which defines the 3-D part geometry. The point cloud data are used to produce a CAD model of the part, from which internal and external dimensions are obtained. Beginning with the CAD model, parts can be fabricated with computer-aided manufacturing (CAM) techniques, such as numerically controlled machining and rapid prototyping methods.

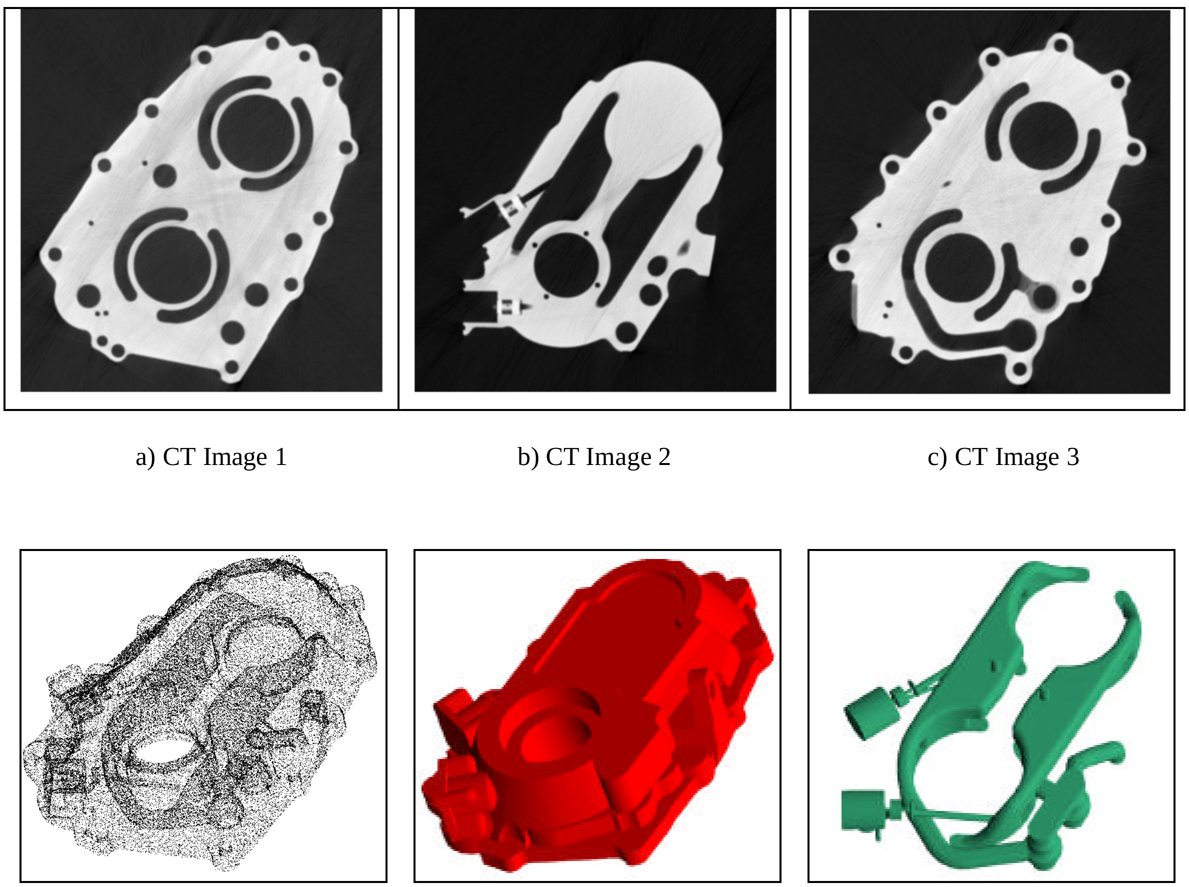
CT-based reverse engineering offers many advantages over conventional methods, especially for complex parts with internal structure:

- Provides a dense data set for accurate measurement regardless of part complexity
- Produces a digital dataset that can be input directly to CAD/CAE/CAM software
- Fully nondestructive, non-contact method without risk to fragile parts
- Insensitive to surface condition or finish
- Set-up is the same regardless of part geometry
- Can be highly automated with limited manual labor

The Konoscope is uniquely qualified to nondestructively capture 3-D part geometry, which is essential for the REMAPP process and agile manufacturing.

ARACOR has demonstrated the technical and economic value of REMAPP technology for low-cost, efficient manufacturing of metal castings. In one project, the REMAPP process was used to design tooling to cast a steering gearbox cover from the Marine Amphibious Assault Vehicle, as

illustrated in Figure 1. A CAD model of the cover was created from a CT inspection of an exemplar cover. Three of the resulting CT images are shown in Figure 1. Both the internal and external surfaces are visible in the point cloud derived from the CT data, Figure 1d. The CAD model constructed from the point cloud data is shown in Figure 1e. A sand mold for casting the part was fabricated using a CAD model of the core, shown in Figure 1f, which was also derived from the CT data. A replica gearbox cover was successfully cast using the REMAPP process. Cost and time savings up to 50% of conventional methods were obtained and the dimensional accuracy was adequate to meet metal casting tolerance requirements.



a) CT Image 1 b) CT Image 2 c) CT Image 3

d) CT-Derived Point Cloud e) CAD Solid Model of Casting f) CAD Solid Model of Core

Figure 1. CT-Assisted Reverse Engineering of a Gearbox Cover Sand Casting

3.0 TECHNICAL APPROACH

The objective of this project was to develop a volumetric CT system with the resolution of a conventional 2-D CT system and the speed of a volumetric system. To meet this objective, ARACOR developed a cone-beam CT system, illustrated in Figure 2. With cone-beam CT, the x-ray beam emerges from the source in a conical shape. The x rays travel through the object and impinge on the area detector. The entire part of interest is illuminated and inspected simultaneously. The views of the object required for CT reconstruction are acquired by appropriate rotation and translation.

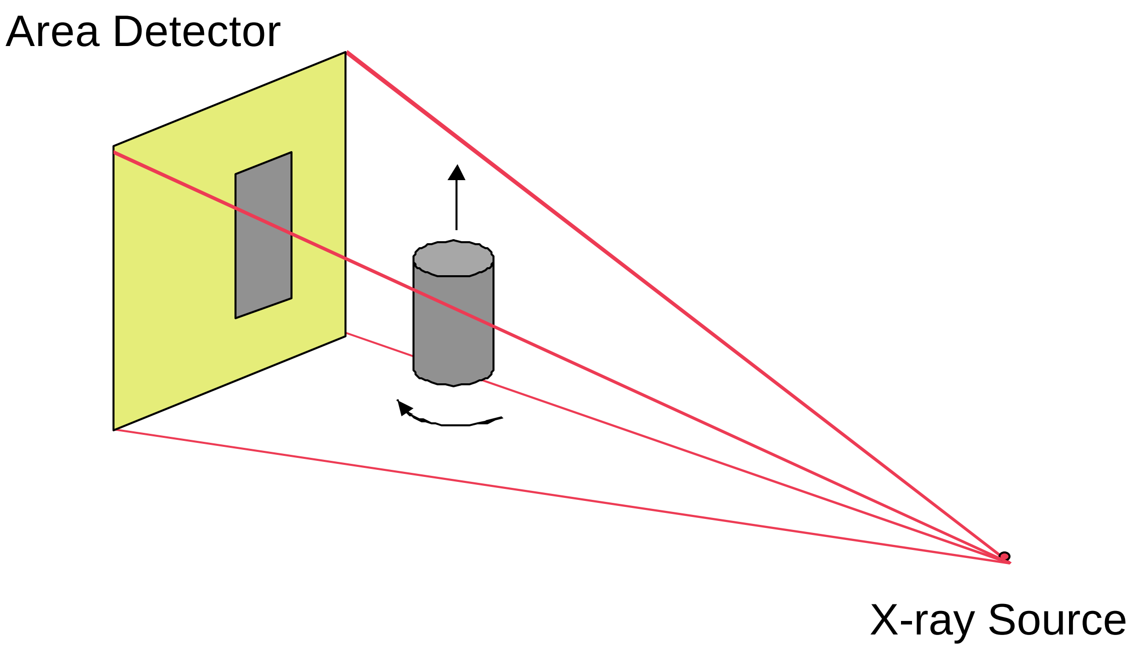


Figure 2. Cone Beam CT System

Table 1 lists the design performance targets that were defined during the project for the volumetric CT system.

Table 1. Design Performance Targets

Feature	**Value**	
	50 mm Field of View	**250 mm Field of View**
Image Size	512 x 512 x 512	512 x 512 x 512
Pixel Size	0.1 mm	0.5 mm
Resolution (FWHM*)	0.2 mm	1.0 mm
Dimensioning Accuracy	0.025 mm	0.050 mm

* Full width half max

Achievement of these performance targets in the cone-beam CT system depended on developing and integrating a number of specific technical improvements:

- A bright x-ray source
- A high-performance area detector
- A scan geometry to acquire high-resolution, volumetric CT data
- A methodology for reconstructing large, 3-D data sets

Each of these improvements was accomplished during the project, as described in Sections 3.1 through 3.4.

The original technical approach included a demonstration of the volumetric CT system in a REMAPP application. The plan was to

- Capture the 3-D geometry of a part using the new volumetric CT system
- Convert the CT data to a CAD model
- Define mold tooling and casting process parameters based on CAE
- Fabricate mold tooling via rapid prototyping
- Cast a replicate part

The demonstration was cancelled because full funding for the project was not available.

3.1 BRIGHT X-RAY SOURCE

The bright x-ray source was achieved by purchasing a customized x-ray source from a commercial supplier and integrating it with an ARACOR diamond anode BRATT (BRight

Anode Transmission Target) target developed for this application. The BRATT target has a transmission geometry with a tungsten target and diamond substrate.

Unfortunately, the FeinFocus 225 kV/320W micro-focus x-ray source cannot be operated at full capacity for any reasonable length of time. It shuts down periodically and displays the diagnostic message, “Generator Breakdown.” The problem appears to be caused by arcing in the x-ray source. The source was returned to FeinFocus and their service technicians spent a considerable amount of time at ARACOR. However, all efforts to overcome the problem have been unsuccessful. Therefore, the source was de-rated and is being operated at a maximum of 160V/200W to reduce the incidence of premature shutdown. For a larger spot size, 300W operation can be achieved. In spite of the problems with the FeinFocus source, ARACOR’s diamond anode BRATT target has had stable operation at the reduced power load.

In 2-D CT, most of the x rays that are scattered from an object are removed by restrictive collimation at the detector. Because detector-side collimation is not practical in 3-D CT, scatter from an object can significantly degrade image contrast. Therefore, ARACOR incorporated source-side slice collimators in the volumetric CT system to reduce the amount of scatter in the image. The effectiveness of these collimators has not been quantitatively measured.

3.2 AREA DETECTOR

The volumetric CT system utilizes a 3-D cone beam rather than a 2-D fan beam of x rays. Therefore, the system requires an area detector with scatter-rejection capability, superior contrast sensitivity and dimensional accuracy. Components of the area detector include a CCD camera and optics, fluorescent screen (scintillator), and scan control software. An appropriate commercial CCD camera and lens were purchased for the area detector. For different sized objects, the camera and optics adjust to maximize the number of pixels across the projected image of the scanned object. For the Konosocope, the largest object (200-mm diameter) would be projected to about 265 mm on the scintillator, while the projection of the smallest object (100-mm diameter) would only be half as large. Therefore, the CCD camera in the Konoscope can “zoom” in or out so that the projected image will fill the 1024 x 1024 optical field of the camera. As a result, the highest resolution is achievable for the full range of object sizes. A convenient, semi-automated technique was developed to recalibrate the system following changes in the field of view.

The scintillator was initially designed as a CsI (Tl) fluorescent screen. However, problems were encountered fabricating a high-quality CsI (T1) one-piece or tiled screen that did not produce artifacts in the CT data. When these problems could not be overcome, a Gd_2O_2S:Tb screen was successfully fabricated. The Gd_2O_2S:Tb screen has the required quality and uniformity, although it has lower brightness and x ray stopping power than the CsI (T1) design.

3.3 VOLUMETRIC SCAN GEOMETRY

Fundamental to the volumetric CT system is the ability to acquire 3-D CT data, rather than data one slice at-a-time. This required the development of a volumetric scan geometry, i.e., a way to move the part relative to the x-ray source to obtain the required volumetric image data. The original plan to combine two, orthogonal scans proved unworkable. A novel helical scan geometry was subsequently devised. During a helical scan, the object is rotated and translated simultaneously, rather than the conventional rotate-translate 2-D CT motion. The advantage of a helical scan is that the scan motion is easy to implement, does not involve repositioning the part, and generates a complete data set.

3.4 RECONSTRUCTION OF 3-D DATA SETS

The 3-D CT system produces very large data sets that must be reconstructed to produce the CT images. Timely reconstruction requires computer hardware and software optimized to treat the large data sets. The initial approach was to develop specially designed accelerator boards for the reconstruction workstation. Lawrence Livermore National Laboratories (LLNL) was tasked to use their Image Matrix Processor technology to develop and fabricate the boards under funding from a separate project. Unfortunately, LLNL delayed implementing their project so long that it could not provide timely inputs to this project. Therefore, development of the accelerator boards was abandoned.

Fortunately, an alternate approach was successful in achieving significant reductions in reconstruction time for 3-D CT data sets. In a cooperative effort with NSF, ARACOR used multithreaded programming to create improved reconstruction software that is optimized for parallel processing. The resulting reconstruction software, running on a workstation with four processors, ran three times faster than previously achievable.

4.0 THE KONOSCOPE

The volumetric CT system developed in this project was named the “Konoscope” from the Greek words *konos,* “cone,” and *scope,* “to look.” A photograph of the Konoscope is shown in Figure 3. The entire system is enclosed in a shielded cabinet measuring approximately 8-feet long x 3-feet wide x 6-feet high. The cabinet is designed to provide easy access to the system for convenient operation and maintenance. Figure 3 shows three compartments that contain the three primary subsystems: the x-ray source in the left compartment, the precision object handling system in the middle compartment, and the area detector in the right compartment. Each compartment is accessed by sliding a lead door, as shown in Figure 3. A view of the object handling system looking toward the x-ray source is shown in Figure 4 and one looking toward the detector is shown in Figure 5. Notice the source-side collimation slits in Figure 4. There are also three computers used for 1) scan control, 2) reconstruction, and 3) analysis, as well as software for each function. The system components are described in Table 2.

A description of the Konoscope is included as Appendix A to this report. Appendix B is a hardcopy of a presentation describing the Konsocope, which will be used to publicize this new CT system.

4.1 OPERATION

The geometry of the source, object handling system and scintillator are shown in Figure 6. The precision handling system provides the capability to move the object in a variety of ways, including helical and conventional rotate-only motions. The area detector components are illustrated schematically in Figure 7. By varying the camera’s field of view, the system can be configured to image objects between 100 mm and 200 mm in diameter. A semi-automated technique is used to recalibrate the system following changes in the field of view.

Figure 3. The Konoscope

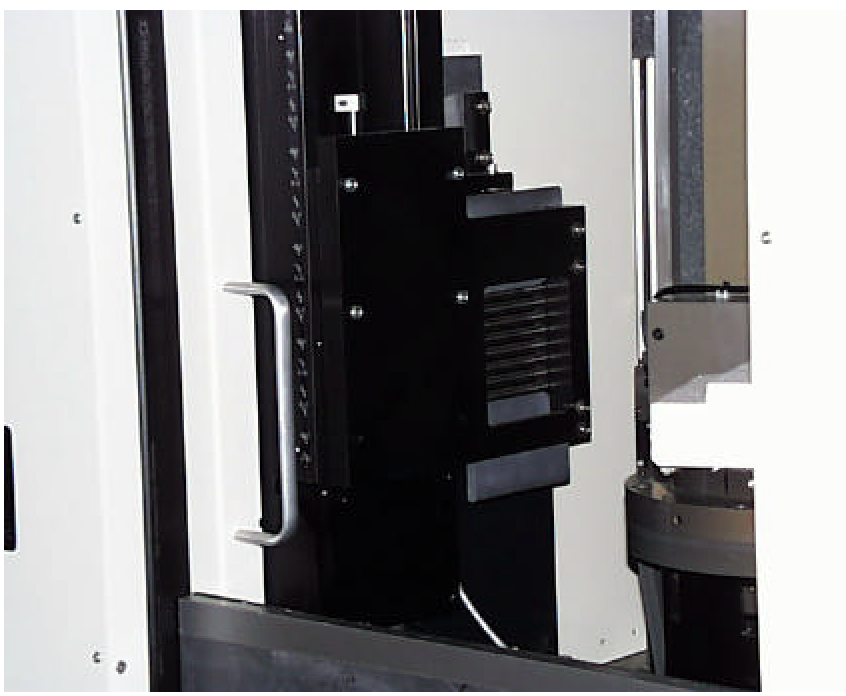


Figure 4. The Object Handling System Looking Toward the X-ray Source

Figure 5. The Object Handling System Looking Toward the Detector

Table 2. Konoscope Components

Component	Description
X-ray Source	• FeinFocus Model FXS-225.50 • Demountable microfocus source • 160 kV (derated) and 300 W maximum • 5 µm – 1 mm adjustable spot size • ARACOR diamond anode BRATT target
Object Handling System	• Dover airbearing tables • 360° rotation • 295-mm elevation • 6-µm position accuracy
Screen	• 350 mm x 350 mm • $Gd_2O_2S:Tb$
Camera and Optics	• Photometric PXL W/10242 CCD 16 bit digital camera • Canon EF 50mm f/1.0 lens
Enclosure	• 8.5 ft x 2.9 ft x 6.0 ft • Cabinet with built-in shielding
Scan Control Computer	• Apple Macintosh 7600/132 • 128 MB RAM • 1.2 GB hard drive • 17 GB hard drive • IP Lab Spectrum image display/analysis software • National Instruments LabView-based control software • ARACOR LVCam camera interface software
Analysis Computer	• Silicon Graphics Indigo 2 • R10000 CPU • 2 MB Cache • 128 MB RAM • 4 GB hard drive • 250 MHz clock speed
Reconstruction Computer	• Silicon Graphics Origin 200 • 4 CPUs • 2 GB RAM • 54 GB Disk

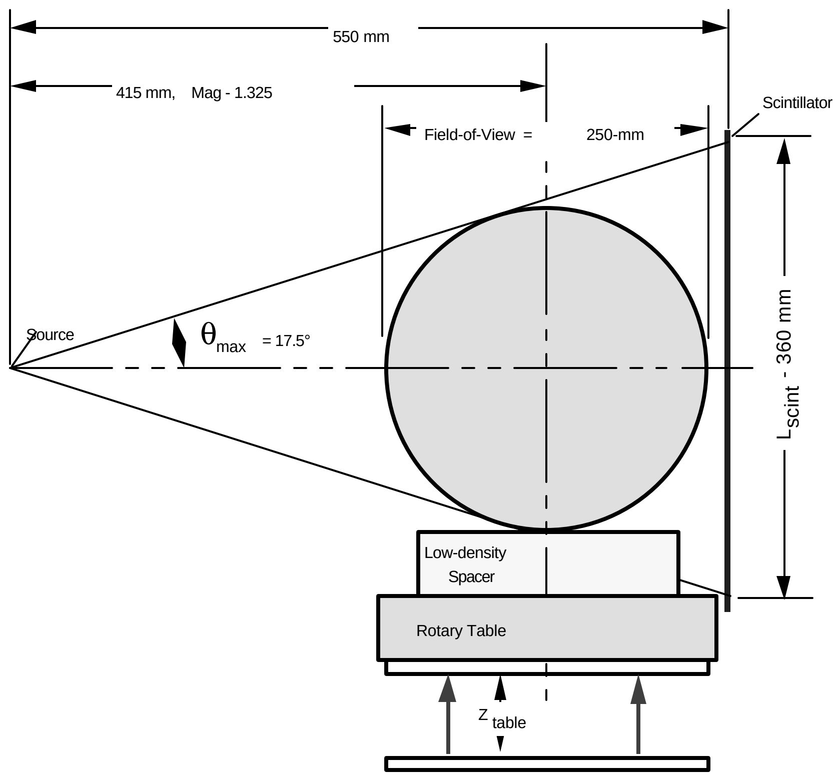


Figure 6. Konoscope Source-to-Scintillator Geometry

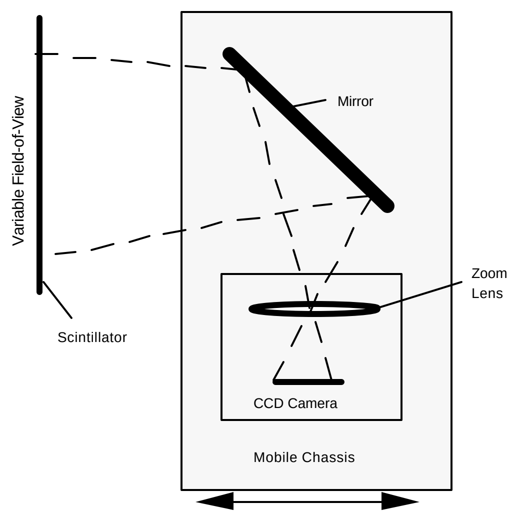


Figure 7. Konoscope Detector

The Konoscope provides the flexibility to perform CT scans with different resolutions, scan geometries, and reconstruction algorithms. Table 3 lists the available combinations of these capabilities.

Table 3. Scan Geometries and Reconstruction Algorithms

	Resolution		
Scan Geometry	**512**	**1024**	**2048**
2-D Rotate Only	X	X	X
3-D Rotate Only	X	X	
3-D Helical	X	X	
Reconstruction Algorithm	X	X	X
IFRT[1]	X	X	X
Back Projection	X	X	
Feldkamp	X	X	
Helical Feldkamp	X	X	
VOIR[2]			

[1] Inverse Fourier Reconstruction Technique
[2] ARACOR's Volumetric Image Reconstruction algorithm

4.2 PERFORMANCE

Table 4 summarizes the performance of the Konoscope based on scans of resolution phantoms. The actual performance can be compared with the design targets listed in Table 1.

Table 4. Konoscope Performance

	Value	
Feature	**100 mm Field of View**	**200 mm Field of View**
Image Size	1024 x 1024 x 1024	1024 x 1024 x 1024
Pixel Size	0.1 mm	0.2 mm
Resolution (FWHM*)	0.25 mm	0.45 mm
Dimensioning Accuracy	0.025 mm*	0.050 mm*

* estimate

The field of view (100 mm to 200 mm) does not cover as wide a range as originally planned (50 mm to 250 mm) due to mechanical constraints in the camera carriage design. However, the multithreaded reconstruction software enabled 1024 x 1024 x 1024 images, rather than 512 x 512 x 512 images. The smaller pixels in the 1024 images account for the improved spatial resolution. At a 200-mm field of view, the 0.45-mm resolution is 100% better than the 1.0-mm target value

at a 250-mm field of view. The finer pixelation and resolution will provide smoother surfaces and finer detail than would otherwise be possible. Although the dimensional accuracy has not been quantified, the improved spatial resolution is expected to be reflected in improved accuracy.

Table 5 lists Konoscope scan and reconstruction times for Feldkamp and VOIR reconstructions of 512 x 512 x 512 and 1024 x 1024 x 1024 images. The input and output file sizes for reconstructing these 3-D CT data sets are very large, as shown in Table 6. Reconstruction of 512 images is faster, in part, because the files are small enough to be processed in RAM. Reconstruction times for 1024 images can be improved by adding parallel processors and by future advances in computational speed.

Table 5. Scan and Reconstruction Time

		Time, Hours		
Reconstruction	**Size**	**Scan**	**Reconstruction**	**Total**
Feldkamp	512 x 512 x 512 1024 x 1024 x 1024	1.5 5	0.5 11	2.0 16
VOIR	512 x 512 x 512 1024 x 1024 x 1024	7 20	1.5 76	8.5 96

Table 6. File Sizes

		File Size, GB	
Reconstruction	**Size**	**Reconstruction Input**	**Reconstruction Output**
Feldkamp	512 x 512 x 512 1024 x 1024 x 1024	0.25 2.0	0.25 2.0
VOIR	512 x 512 x 512 1024 x 1024 x 1024	0.75 6.0	0.25 2.0

4.3 EXAMPLES

A nautilus shell, an intricate aluminum casting, and a graphite composite test sample were scanned with the Konoscope. CT images of these objects are presented in this section.

4.3.1 Chambered Nautilus Shell

A CT slice through a chambered nautilus shell, showing the familiar internal structure, is shown in Figure 8. Figure 9 is a 3-D rendering of the shell from the volumetric CT data. The longest dimension of the shell is approximately 14 cm.

4.3.2 Aluminum Casting

Figure 10 shows a photograph of the aluminum casting on the left and a volumetric image of the CT data on the right. The casting measures approximately 95-mm long x 45-mm wide x 55-mm high.

4.3.3 Graphite Composite Test Sample

The graphite composite test sample, approximately 38-mm long x 38-mm wide x 19-mm tall, is shown in Figure 11. Figure 12 is a volumetric image of the sample created from the CT data. During the test, material was removed from one end of the sample. The CT examination revealed lower density material in this region, which appears as darker material in the cross-sectional view shown in Figure 13. Cracks oriented through the thickness of the sample are also visible in Figure 13. High-density inclusions in the sample appear as white dots in Figure 14.

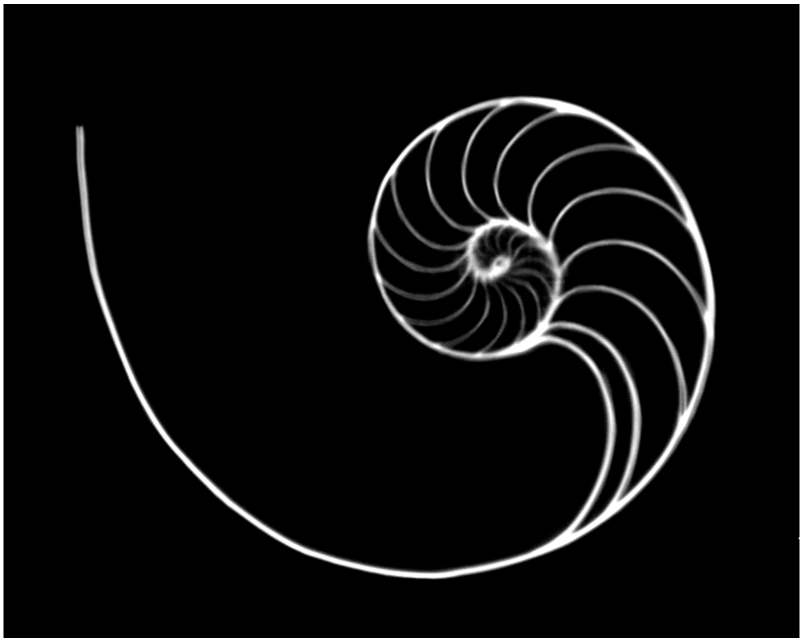


Figure 8. CT Slice of the Chambered Nautilus Shell

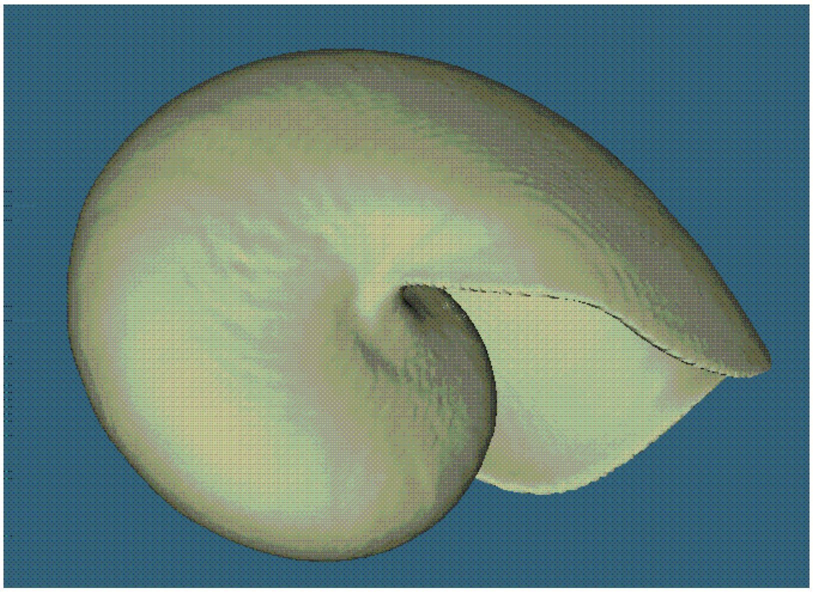


Figure 9. Volumetric Image of the Chambered Nautilus Shell

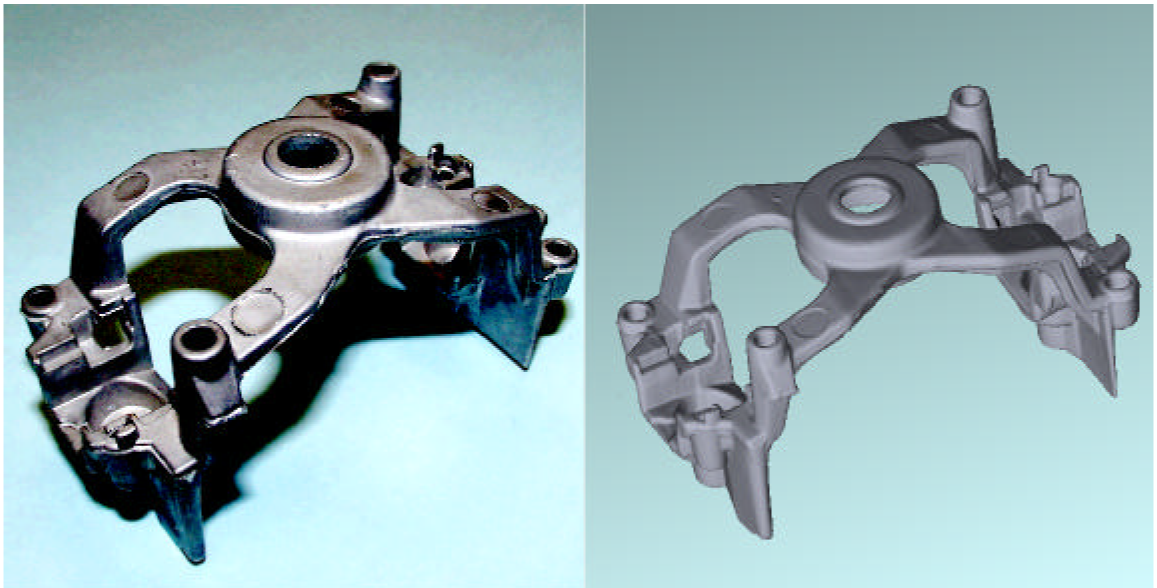


Figure 10. Photograph and Volumetric Image of the Aluminum Casting

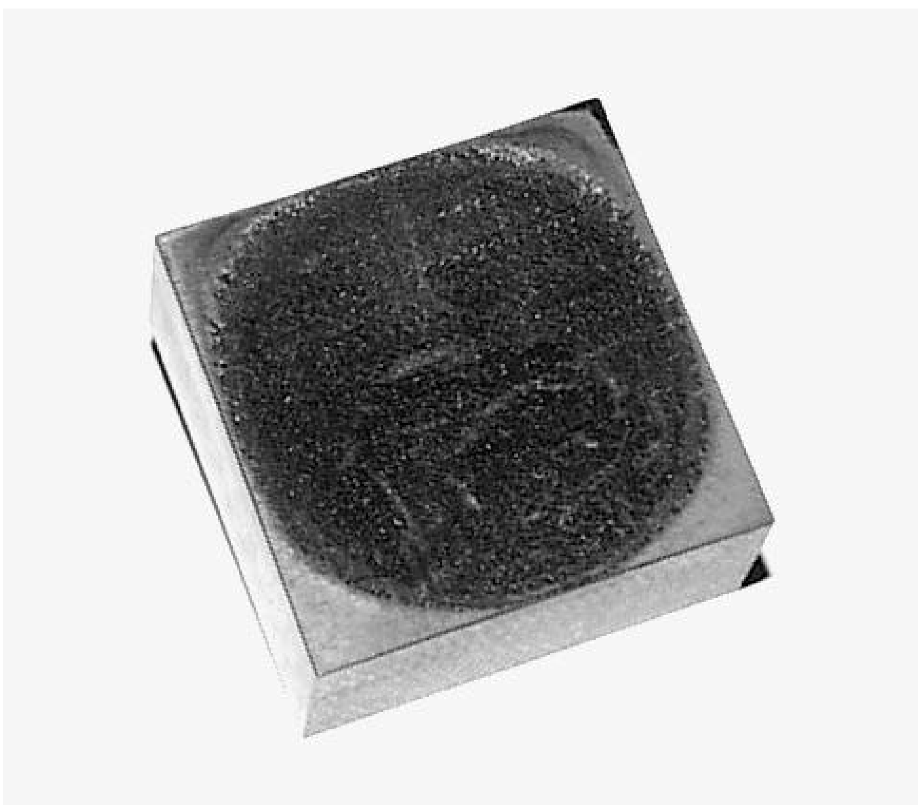


Figure 11. Photograph of the Graphite Composite Test Sample

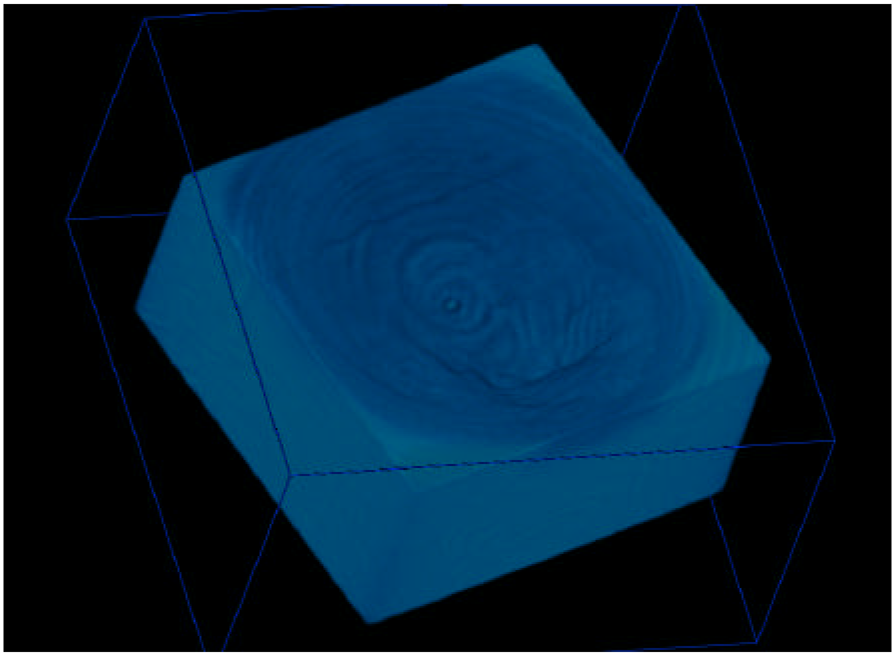


Figure 12. Volumetric Image of the Composite Test Sample CT Data

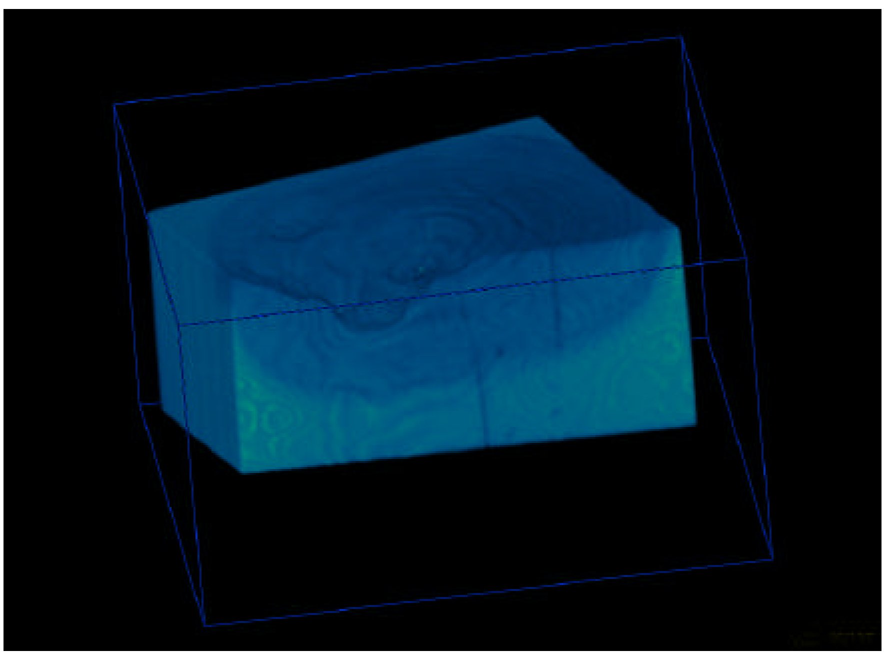


Figure 13. Density Variation and Cracks in the Composite Test Sample

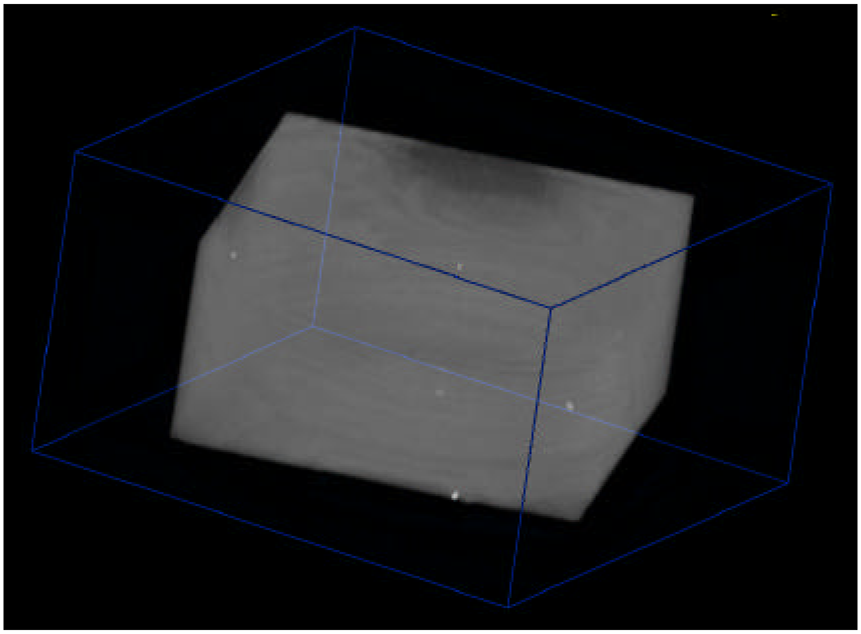


Figure 14. Inclusions in the Composite Test Sample

5.0 CONCLUSIONS

The principal result of this project is the Konoscope, the first practical volumetric CT system with the accuracy and speed required to support demanding, high-resolution CT applications. The success of the project is due to the following technical developments:

- A bright x-ray source using the ARACOR diamond anode BRATT target
- A high performance area detector
- An accurate and practical helical scan geometry
- Reconstruction of 3-D data sets by parallel processing using optimized software

The Konoscope is capable of scanning objects from 100 mm in diameter with 0.25-mm resolution up to 200 mm in diameter with 0.45-mm resolution. A variety of 2-D and 3-D scan geometries and reconstruction algorithms are available. Creating volumetric CT images with the Konoscope is significantly faster than with conventional 2-D CT systems. In one day, several parts can be scanned and 512 x 512 x 512 volumetric images produced. Even 1024 x 1024 x 1024 images, which are required for the most demanding CT applications, can be produced in one day. With the Konosocope, reconstruction rather than scanning is the time-critical operation, primarily due to processing of very large volumetric data sets. Reconstruction times for 3-D CT will improve, as faster computational hardware becomes available.

The performance of the Konoscope can be improved by pursuing the following enhancements:

1. Accelerate reconstruction by using alternative algorithms, optimized numerical approaches, and faster hardware.
2. Improve the imaging chain by
    - Better light collection efficiency
    - Faster CCD readout
    - Higher energy, more reliable x-ray source
    - Novel area detectors
    - Improved fluorescent screens, such as CsI (T1) and amorphous silica.

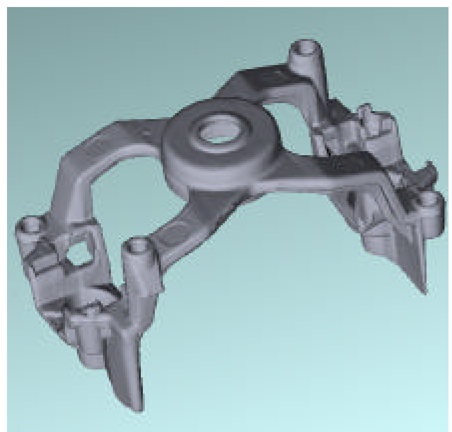
A demonstration of the Konoscope as a practical tool for agile manufacturing can be accomplished by performing the initially planned REMAPP exercise.

APPENDIX A. KONOSCOPE DESCRIPTION

Konoscope™ Volumetric CT System

ARACOR has developed the Konoscope™ volumetric x-ray computed tomography (CT) system. Unlike conventional CT systems, which slowly take data one slice-at-a-time, the Konoscope uses a cone beam of x rays to acquire data from an entire volume at one time. As a result, CT inspection time is significantly reduced. The first Konoscope, which was developed under Air Force sponsorship, can inspect objects up to 200 mm in diameter in 3 hours, which is an order of magnitude faster than a conventional 2-D CT system. This Konoscope has a minimum spatial resolution of 250 µm and maximum x-ray energy of 160 kV. It is a fully-shielded cabinet system measuring 8-feet long x 3-feet wide x 6-feet high. ARACOR offers a variety of 2-D and 3-D image reconstruction algorithms, including back projection, Feldkamp, and helical Feldkamp. A Konoscope for scanning objects up to 4 cm in diameter with 15 to 80-µm resolution will be delivered in early 2000.

Konoscope



Konoscope Image of a Metal Casting

X-ray computed tomography is a radiographic inspection method that uses a computer to reconstruct an image from cross-sectional views through an object. The resulting image accurately represents the internal and external geometry of the object, unlike conventional x-ray techniques, in which features are superimposed onto a single plane. CT can also provide information about the density and composition of material in the object. Therefore, CT can be used for inspection, to detect anomalies; for metrology, to confirm dimensions; and for reverse engineering, to reproduce identical parts.

ARACOR is the leading US supplier of high-energy x-ray imaging systems. ARACOR delivered the first industrial CT system in 1983 and since 1988 delivered every high energy CT system in the US. ARACOR is the leader in developing state-of-the-art x-ray imaging systems to meet a wide-variety of industrial inspection needs.

For more information about the Konoscope and to discuss your x-ray inspection requirements, please contact ARACOR at 408-733-7780.

APPENDIX B. KONOSCOPE PRESENTATION

ARACOR

The Konoscope™ Volumetric CT System

Outline

ARACOR

- What Is a Konoscope?
- Methodology
- Design
- Performance
- Examples

Motivation

ARACOR

Designed for practical, high resolution applications

- 3-D geometry capture
- Reverse engineering
- Metrology
- Inspection

ARACOR

Development Funding

- AFRL/ML
- DARPA
- NSF
- State of California
- ARACOR

ARACOR

Konoscope is Unique

- Acquires volume of CT data at one time, instead of slice-by-slice
- High resolution
- Practical CT inspection times, even for 1024^3 images

Konoscope vs 2-D CT

ARACOR

Konoscope	2-D CT
• Data acquired at one time	• Data acquired slice-by-slice
• Helical scan	• Rotate-translate scan
• Practical scan times	• Long scan times
• 3-D data set	• Series of 2-D data sets
• Reconstruction time driver	• Scanning time driver
• High resolution	• High resolution

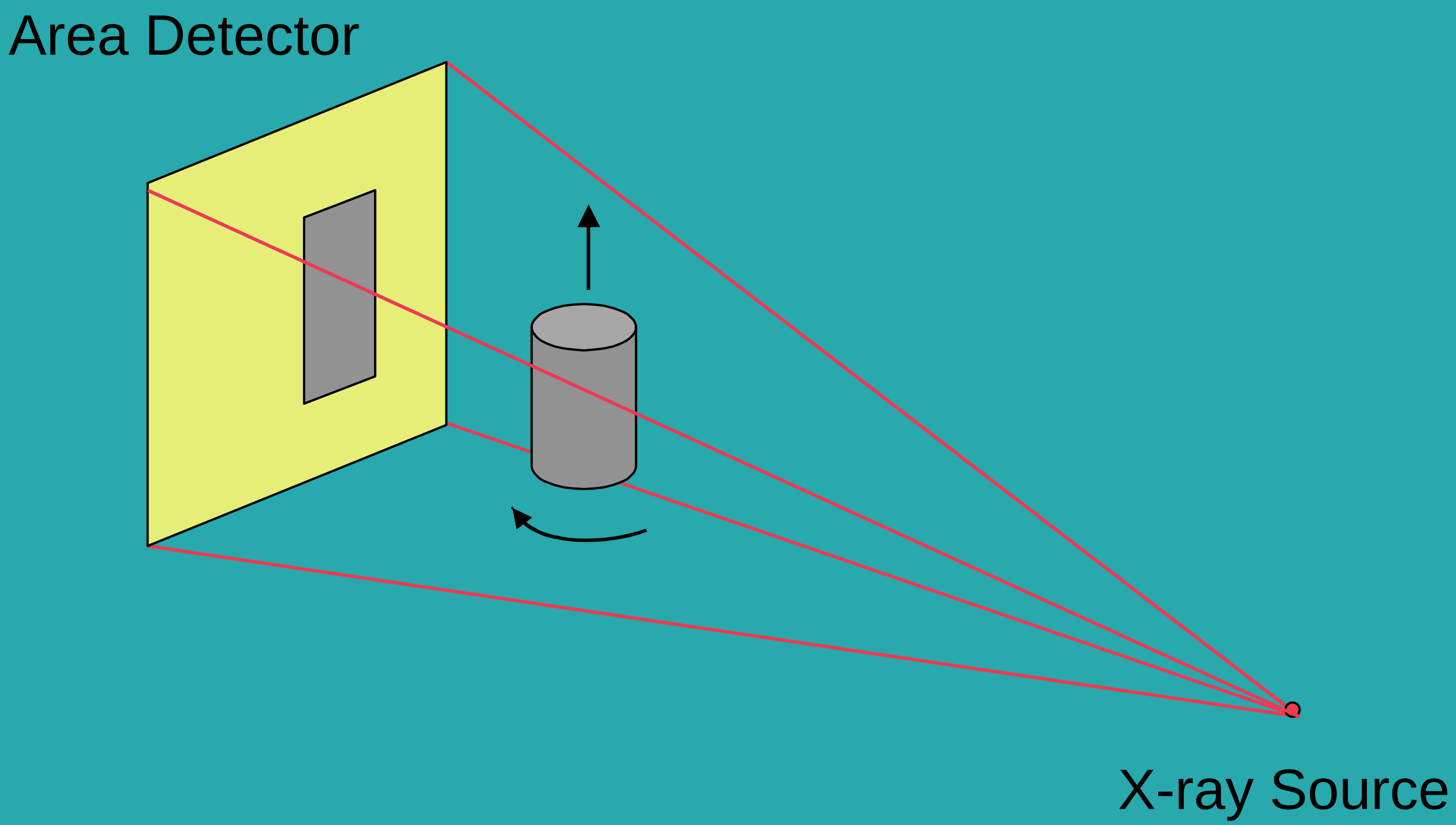
Methodology

ARACOR

- X-ray cone beam
- Area detector
- Helical scan
- 3-D reconstruction

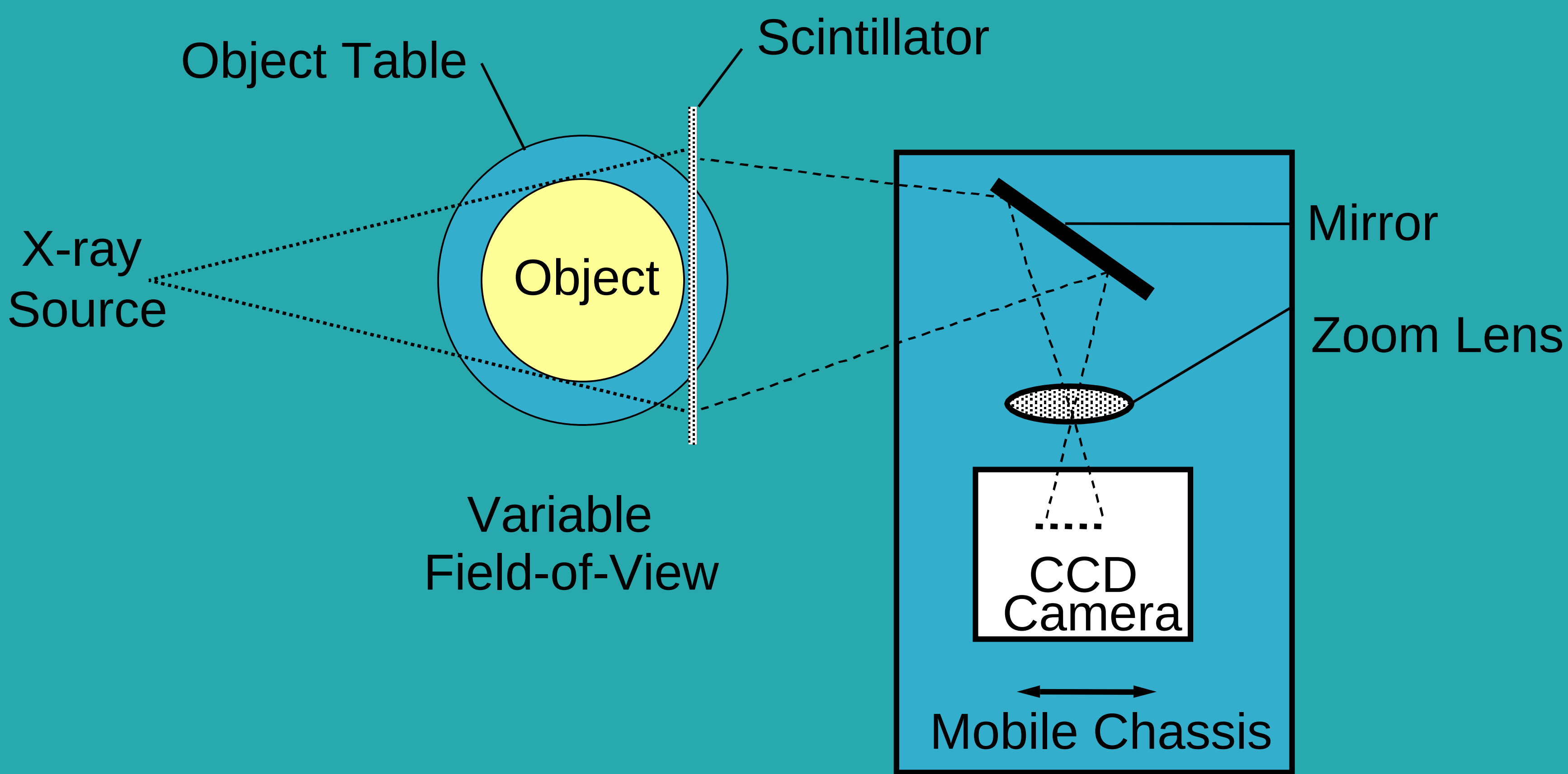
Cone-Beam Geometry

ARACOR



Configuration

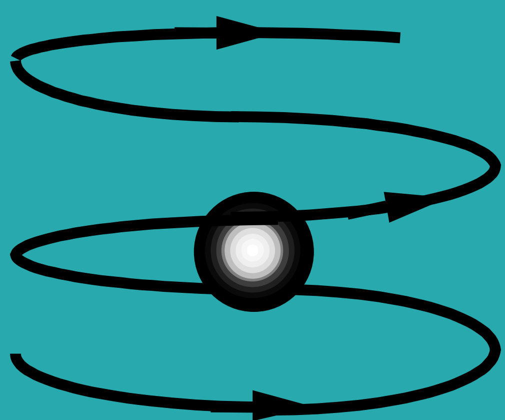
ARACOR

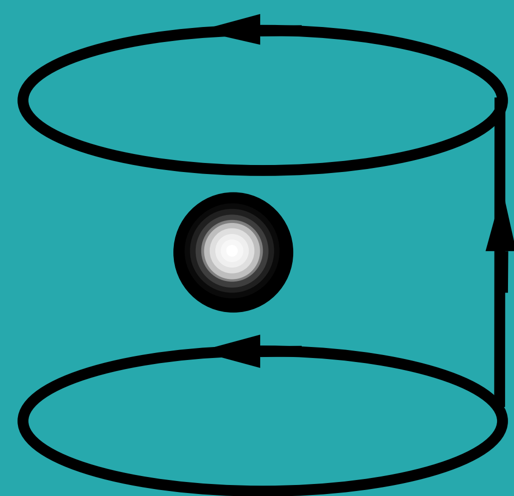


Scan Geometries

ARACOR

Helical | **Rotate-Translate**





Konoscope | **2-D CT**

Flexibility

ARACOR

- 2-D and 3-D scan geometries
- Variety of reconstruction algorithms
- 512^3, 1024^3, and 2048^3 images

Konoscope Designs

ARACOR

Feature	Prototype	Micro
Field of View	100 - 200 mm	10 - 400 mm
Resolution	0.25 – 0.45 mm	0.02 – 0.2 mm
Dimensional Accuracy	0.25 mm	TBD
Image Size	2048 x 2048	2048 x 2048
X-ray Energy	160 kV	130 kV

Computing Power

ARACOR

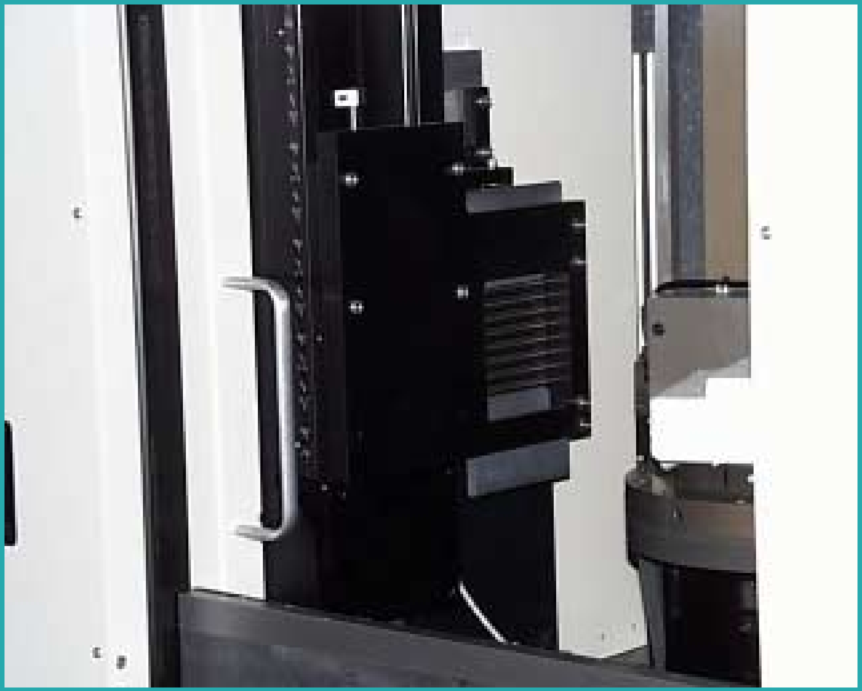
- Scan Control
  - –Macintosh G3
- Reconstruction
  - –SGI Origin with 4 CPUs
- Analysis
  - –SGI Indigo

The Konoscope

ARACOR

Object Handling System

ARACOR



Source Side

Detector Side

ARACOR

Performance

	Time, Hours		
Pixels	Scan	Reconstruct	Total
512 x 512 x 512	1.5	0.5	2.0
1024 x 1024 x 1024	5	11	16

Feldkamp reconstruction algorithm

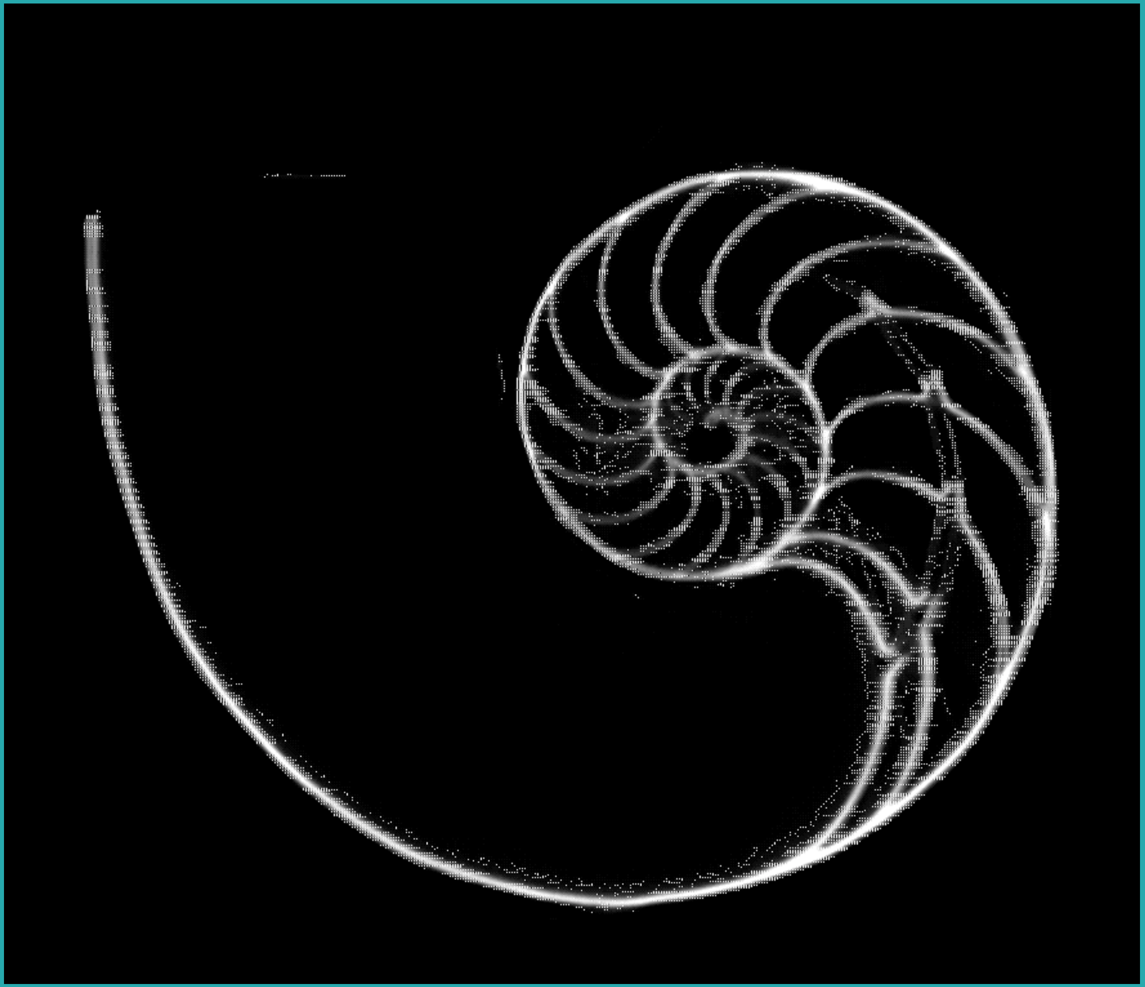
ARACOR

Examples

- Nautilus Shell
- Aluminum Casting

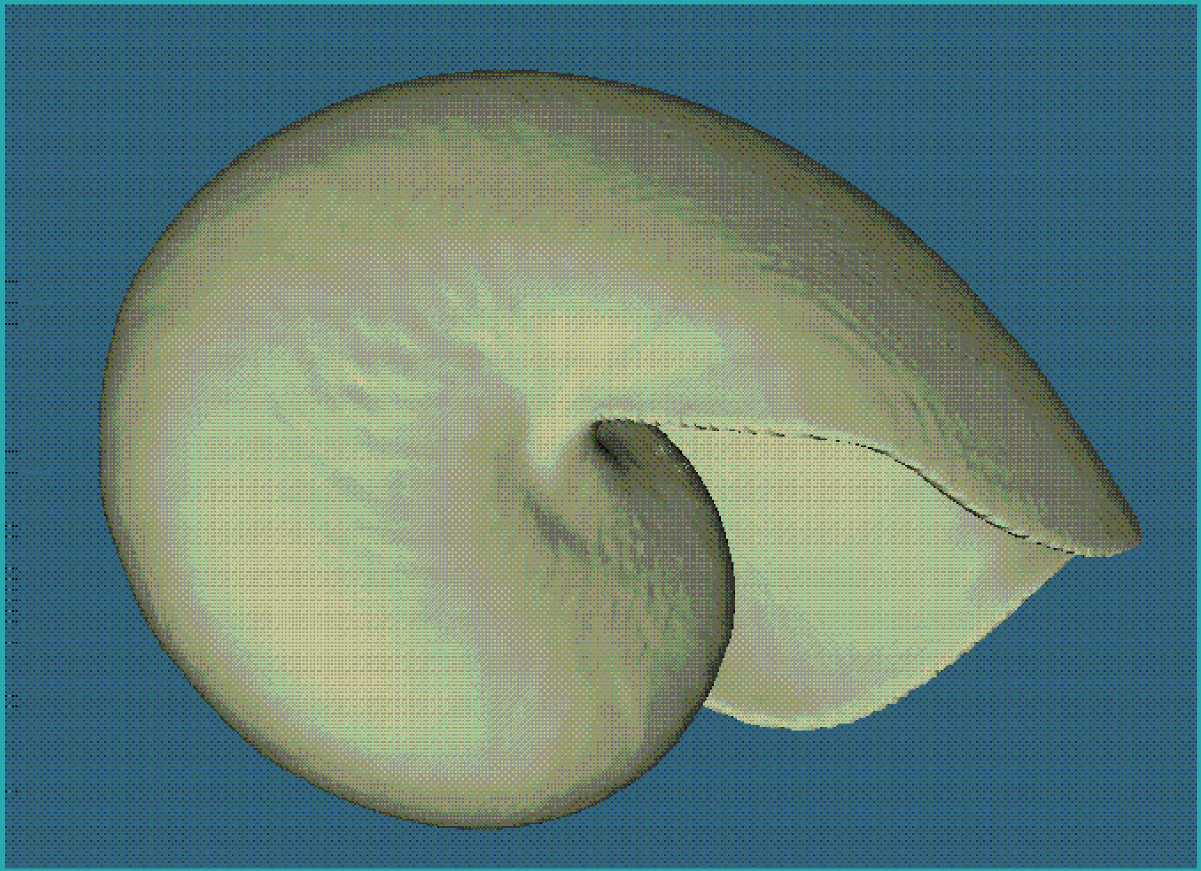
Nautilus Shell Slice

ARACOR



Rendered Shell

ARACOR



Aluminum Casting

ARACOR

Photograph **3-D Image**

ARACOR

Applications

- Metrology
- Reverse Engineering
- Agile Manufacturing
- Nondestructive Testing
- Imaging

Future Improvements

ARACOR

- Higher X-ray energy
- Higher resolution
- Faster reconstruction

Konoscope Advantages

ARACOR

- Reduced scan times
- Practical high resolution scanning
- Supports most demanding CT applications